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# LNG CONTAINMENT SYSTEM AND METHOD OF ASSEMBLING LNG CONTAINMENT SYSTEM

## CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of international application PCT/US05/17363, filed 17 May 2005, and U.S. Provisional Application 60/572,736, filed 20 May, 2004.

## BACKGROUND

### Field of the Inventions

[0002] Embodiments of the present invention generally relate to the storage of large fluid volumes. More particularly, embodiments of the present invention relate to tank designs for holding hydrocarbons. In addition, embodiments of the present invention relate to the manufacture of an LNG containment system.

### Description of Related Art

[0003] Clean burning natural gas has become the fuel of choice in many commercial and consumer markets around the industrial world. Such natural gas is oftentimes transported across oceans from the sites of production to consuming nations. Such transportation of natural gas typically occurs over long distances using large-volume marine vessels.

[0004] In order to facilitate transportation the gas is taken through a liquefaction process. The liquefied natural gas, or "LNG", is formed by chilling very light hydrocarbons, e.g., hydrocarbons comprised primarily of methane, to approximately -163° C, where it is stored at ambient pressure in special cryogenic tanks. Due to its low critical temperature, continued refrigeration is desired for LNG transportation and storage.

**[0005]** Upon delivery to an import terminal, the LNG is typically stored for later use and delivery to domestic markets. Experience shows that bulk storage of liquefied natural gas is most economical when stored in its fully refrigerated state, and at its bubble point at or near atmospheric pressure. The boiling point of LNG at one atmosphere is approximately -163° C. To accommodate this condition, insulated storage tanks are employed. The LNG storage tanks typically have a primary container and a surrounding secondary container.

**[0006]** For large volume storage of LNG, two distinct types of tank construction are widely used. The first of these is a flat-bottomed, cylindrical, self-standing tank that typically uses a 9% nickel steel for the inner tank and carbon steel, 9% nickel steel, or reinforced/prestressed concrete for the outer tank. The second type is a membrane tank wherein a thin (e.g. 1.2 mm thick) metallic membrane is installed within a cylindrical concrete structure which, in turn, is built either below or above grade on land. A layer of insulation is typically interposed between the metallic membrane, e.g., of stainless steel, and the load bearing concrete cylindrical walls and flat floor.

**[0007]** In the context of the cylindrical, self-standing LNG tank, and from a safety and environmental standpoint, it is preferred that the tank have "full containment." A "full containment" system requires that the outer secondary container hold both liquid and its vapor should the liquid escape from the primary container. The full containment system should also be configured to permit the controlled release or withdrawal of these fluid products from the system. While structurally efficient, cylindrical tanks in their state-of-practice designs are difficult and time consuming to build. LNG storage systems using self-standing 9% nickel steel tanks may require up to 36 months for construction. On many projects, this causes undesirable escalation of construction costs and length of construction schedule.

**[0008]** A need exists for a full containment LNG storage system that provides liquid and vapor integrity in the event of primary container leakage, and that can be efficiently fabricated. A need further exists for an improved method of fabricating a secondary container, such as an LNG container. A need further exists for

prefabricated wall and roof panels that may be brought to a construction site for efficient erection of secondary container walls and roof structure.

## SUMMARY

[0009] An LNG full containment system is provided. The LNG system generally comprises a floor slab, a primary container positioned on the floor slab, and a secondary container positioned around the primary container. The secondary container preferably incorporates the floor slab as part of its structure. The primary container is insulated in order to maintain a desired temperature within the primary container. For example, an insulating material such as pearlite is placed in the annulus between the outer side of the inner container and the inner side of the outer container.

[0010] The secondary container generally comprises a first end wall, a second end wall, and at least two side walls. At least one of the walls is fabricated from a plurality of prefabricated wall panels. Each of the prefabricated wall panels is fabricated from a combination of concrete and steel.

[0011] Preferably, each of the prefabricated wall panels includes a thin concrete plate having a longitudinal axis, and at least one steel beam connected to the concrete plate along the longitudinal axis of the concrete plate. In one embodiment, each wall panel includes a moisture barrier directly attached to the concrete plate opposite the at least one steel beam. Preferably, each wall panel is insulated by placing an insulation layer on the concrete plate or the moisture barrier, if a moisture barrier is installed. The insulation layer is preferably covered by a liner that is impervious to LNG and its vapor and that can withstand the cryogenic temperature of LNG such as thin sheets made of 9% Ni steel or stainless steel. The wall panels are preferably prefabricated offsite and then transported to the construction site where they are adjoined together in side-by-side fashion.

[0012] In another embodiment, a shallow-arch roof is provided that is also fabricated from a combination of steel and concrete roof panels. The roof panels also

are preferably prefabricated offsite and then transported to the construction site where they are adjoined together in side-by-side fashion.

**[0013]** The present invention also provides a method for assembling an LNG full containment system. In one embodiment, walls and a roof as described above are provided. The walls are optionally constructed from wall panels prefabricated off-site. The prefabricated panels are then delivered to the tank site where they are adjoined together in side-to-side fashion according to desired dimensions.

**[0014]** In one embodiment of the method, a floor slab is first poured at the construction site. The slab is fabricated at least in part from concrete. A first planar end wall is erected on the floor slab. In addition, first and second planar side walls are erected on the floor slab, the first and second planar side walls being connected to the first end wall at opposite ends but being angled relative to the first end wall to leave an opening for receiving a second planar end wall so that a polygon having at least four sides may be formed. A roof structure is also constructed. The roof structure that covers the polygon formed by the end and side walls to provide a roof for a secondary container.

**[0015]** In accordance with the method, a primary container is also constructed. The opening within the secondary container is used as a means of access into the secondary container. In one aspect, one or more substantially completed primary containers is moved into the secondary container. Finally, a second planar end wall is erected so as to enclose the primary container within the secondary container.

## <u>BRIEF DESCRIPTION OF THE DRAWINGS</u>

**[0016]** Figure 1 presents a perspective, cutaway view of a containment structure. In the illustrative drawing of Figure 1, an external "secondary container" of the containment structure is seen. In addition, an inner "primary container" is seen in the cutaway portion of the drawing.

**[0017]** Figure 2 provides an additional perspective view of an illustrative secondary container. A portion of an upper roof structure is peeled away to show roof

trusses. A plurality of steel beams can be seen as part of the vertical end and side walls of the secondary container.

**[0018]** Figure 3 shows a series of individual prefabricated panels that may be used for assembling vertical walls of the secondary container, in one embodiment. The panels are mated in side-to-side fashion.

**[0019]** Figure 4 provides a top view of a portion of the panels of Figure 3.

**[0020]** Figure 5 presents a perspective view of a single panel from Figure 3. In one embodiment, the single, prefabricated panel represents the smallest building block of the combination wall units.

**[0021]** Figure 6 is a perspective view of the panels of Figure 3, seen from the opposite side. Here, the face or "inner surface" of the combination panels is seen, with the panels again being mated in side-to-side fashion.

**[0022]** Figures 7A-7F present sequential steps for assembling a wall panel as may be used in the construction of walls for the secondary container, in one embodiment.

**[0023]** Figure 7A shows the placement of a steel I-beam in a jig.

**[0024]** Figure 7B shows illustrative formwork for the placement of concrete during fabrication of the wall panels.

**[0025]** Figure 7C shows reinforcing cages being laid in the formwork of Figure 7B.

**[0026]** Figure 7D shows embedded plates and other aids used for the attachment of a moisture barrier, an insulation layer and the liner plate being placed alongside the steel reinforcing cages of Figure 7C.

**[0027]** Figure 7E demonstrates the pouring of concrete in the formworks containing the steel reinforcing cages, embedded plates and other construction aids of Figure 7D.

[0028] Finally, Figure 7F shows the attachment of various layers over the top surface of the cured concrete plate. Layers may include a moisture barrier layer, an insulation layer and a liner plate placed over the concrete plates of Figure 7E.

[0029] Figure 8 is an enlarged perspective view of a portion of the containment system from Figure 2. Visible in this view are steel trusses with reinforced concrete roof panels being placed there over. Vertical side panels in accordance with the panels of Figure 3 are also visible, supporting the steel roof trusses.

[0030] Figures 9A-9F present sequential steps for construction of a secondary container, in one embodiment.

[0031] Figure 9A shows the formation of a concrete floor slab. In this embodiment, the footprint of the slab is rectangular. In addition, a vertical end wall has been erected over an end of the floor slab using prefabricated wall panels.

[0032] Figure 9B presents the placement of a prefabricated roof panel on the concrete floor slab.

[0033] Figure 9C is a cutaway view of the secondary container. In this step, the two opposing side walls have been erected along the floor slab. In addition, a roof structure has been placed over the span between the two opposing side walls to define the secondary container. A substantially complete primary container is being moved into its position within the secondary container.

[0034] Figure 9D shows the same construction steps of Figure 9C, but shows the secondary container in perspective view without a cutaway section.

[0035] Figure 9E demonstrates that the primary container being moved into the secondary container. Finally, Figure 9F shows the erection of the second vertical end wall to form the enclosed secondary container.

## DETAILED DESCRIPTION

### Definitions

[0036] The following words and phrases are specifically defined for purposes of the descriptions and claims herein. To the extent that a term has not been defined, it should be given its broadest definition that persons in the pertinent art have given that term as reflected in printed publications, dictionaries or issued patents.

[0037] "Primary container" means an inner tank of an LNG containment system.

[0038] "Secondary container" means a tank that envelopes the primary container within an LNG containment system.

[0039] "Vertical panel" means a panel of a tank that is substantially vertical relative to a floor slab on which it is erected. "Panel" refers to any building block made of a combination of at least concrete and steel.

[0040] "End panel" means any substantially vertical panel at an end of a tank.

[0041] "Planar" means substantially planar, and does not exclude a surface that is slightly concave.

[0042] "Moisture barrier" means any sheet of material resistant to fluid penetration. A non-limiting example is a 3 mm sheet of carbon steel.

[0043] "Insulation layer" means any layer of material that provides thermal insulation to a concrete plate. A non-limiting example is a sheet of plywood. Another non-limiting example is a layer of polyurethane foam.

[0044] "Liner plate" means any sheet of material used to line the inner surface of an LNG container.

**Description of Specific Embodiments**

**[0045]** The following provides a description of certain specific embodiments of the present invention:

**[0046]** An LNG full containment system is first provided. The system includes a floor slab; a primary container positioned on the floor slab, the primary container being insulated to hold liquefied natural gas; and a secondary container peripherally positioned around the primary container, the secondary container comprising a plurality of composite walls attached to the floor slab, with each of the composite walls being formed from a plurality of prefabricated wall panels configured to be adjoined in side-to-side fashion. Each of the prefabricated wall panels includes a concrete plate having a longitudinal axis and an outer surface, and at least one steel beam connected to the outer surface of the concrete plate along the longitudinal axis of the concrete plate. Each of the plurality of composite walls of the secondary container has a first end wall, a second end wall, and at least two side walls, with each of the at least two side walls being disposed on opposing sides of the first end wall.

**[0047]** Preferably, each of the prefabricated wall panels further includes a moisture barrier disposed on the concrete plate opposite the at least one steel beam. Preferably, each of the prefabricated wall panels also further includes an insulation layer along the moisture barrier opposite the at least one steel beam, and a liner plate on the insulation layer. The moisture barrier may be fabricated from material selected from the group consisting of: a metallic material and a polymeric material.

**[0048]** The LNG full containment system may have a roof structure that includes a plurality of prefabricated roof panels adjoined in side-to-side fashion, with each of the roof panels including a concrete plate an inner surface, and a steel truss structure connected to the inner surface of the concrete plate.

**[0049]** A method of assembling an LNG full containment system is also provided. In one embodiment, the method includes the steps of pouring a floor slab fabricated at least in part from concrete; erecting a first end wall on the floor slab; erecting first and

second side walls on the floor slab, the first and second side walls being connected to the first end wall at opposite ends, but being angled relative to the first end wall to leave an opening for receiving a second end wall so that a polygonal enclosure having at least four sides may be formed; providing a roof structure that is supported at least in part by the side walls; moving a substantially assembled primary container into the secondary container; and erecting the second end wall so as to enclose the primary container within the secondary container. The step of moving the substantially assembled primary container into the secondary container may be accomplished by using the opening for the second end wall as a means of access into the secondary container

**[0050]** In one embodiment, the polygon is a four-sided polygon, and the first and second end walls and the first and second side walls connect together to form a rectangle. In another embodiment, the polygon is a six-sided polygon, the method further comprises the step of erecting third and fourth side walls on the floor slab, the third and fourth side walls being connected to the first and second side walls, respectively, but also being angled to preserve the opening for receiving the second end wall so that the six-sided polygon may be formed.

**[0051]** In one arrangement, the primary container comprises a plurality of planar, vertical walls, and the method further comprises the step of fabricating the vertical walls of the primary container at the same time that at least one of the side walls of the secondary container is being erected on the concrete floor slab.

**[0052]** In addition, a wall panel for a secondary container is provided. The secondary container is employed with a full containment LNG system. The wall panel may include a concrete plate having an inner surface, an outer surface, and a longitudinal axis; at least one steel beam connected to the concrete plate along the outer surface of the concrete plate, and along the longitudinal axis; and wherein the wall panel is configured so that a plurality of wall panels may be adjoined in side-to-side fashion so as to form a wall of a secondary container for the full containment LNG system. The wall panel preferably has an insulation layer disposed on the concrete plate opposite the at least one steel beam. Preferably, the wall panel also

includes a moisture barrier along the insulation layer opposite the at least one steel beam, and a liner plate on the insulation layer.

**Description of Embodiments Shown in the Drawings**

**[0053]** The following provides a description of specific embodiments shown in the drawings:

**[0054]** **Figure 1** presents a perspective, cutaway view of a containment structure **100**, in one embodiment. The containment structure **100**, in its most general form, comprises an external secondary container **200** and at least one inner primary container **300**. A primary container **300** is seen in the cutaway portion of the secondary container **200**. The primary container **300** is designed to hold liquefied natural gas ("LNG") at cryogenic temperature and in an insulated manner. At the same time, the secondary container **200** is designed to serve as a "back-up" to the primary container **300** in the event that the primary container **300** loses fluid integrity.

**[0055]** A secondary container of an LNG storage system fulfills several functions. During normal operations, the outer, or "secondary" container holds the insulation in place and provides protection to the inner, primary tank against the elements of nature. Under extreme conditions when the inner tank is assumed to fail and no longer able to hold the cryogenic liquid, the outer tank is called upon to hold full contents of the inner tank safely and to permit both controlled withdrawal of the contained liquid and controlled release of the product vapor. In this event, a severe set of loads is imposed on the outer tank. Not only is the outer tank subjected to the hydrostatic loads applied by the liquid now contained by it, but the outer wall is also subjected to a 'thermal shock' loading due to sudden exposure to the very low temperatures of the LNG liquid. The inner wall and floor surfaces of the secondary container experience a sudden and severe drop of temperature while the outer surfaces of the secondary container wall remain exposed to ambient temperature. This causes severe stresses in the secondary container at junctures such as wall-floor interfaces. Thus, a secondary container **200** is preferably designed to accomplish one or more of the following: (1) withstand hydrostatic forces upon fluid leakage from the primary

container **300**, (2) contain liquids that might escape from the primary container **300**, (3) provide gas tightness from gases that will form when liquid escapes from the primary container **300**, and (4) withstand thermal shock created if and when extremely cold fluids from the primary container **300** contact the inner surfaces of the secondary container **200**.

**[0056]** In the arrangement of **Figure 1**, the secondary container **200** defines a polygonal structure having a plurality of walls. More specifically, the secondary container **200** has a first end wall **212** and a second opposite end wall **214**. In addition, the container **200** has at least two opposite side walls disposed intermediate the first **212** and second **214** end walls. One of the side walls is seen at **222**, while a second side wall is on the back side and not directly visible, but is nevertheless referenced at **224**. The secondary container **200** further includes a bottom floor slab **250** and a roof structure **260**. The end walls **212, 214**, the at least two side walls **222, 224,** the floor slab **250** and the roof structure **260** form an enclosure for the primary container **300**.

**[0057]** In the arrangement of **Figure 1**, the polygonal form of the secondary container **200** is a four-sided structure, forming a rectangle. However, the four-sided structure could also be a square. Alternatively, the polygonal form of the secondary container **200** could be formed from more than 4 sides, for example, a six-sided or an eight-sided structure (not shown). In such an arrangement, the secondary container **200** would have additional opposing side walls (not shown) between side walls **222, 224** and end panel **214**, respectively. The various end and side walls may or may not have the same length, and may or may not be precisely linear.

**[0058]** **Figure 2** provides an additional perspective view of an illustrative secondary container **200'**. A rectangular enclosure is again provided. A plurality of steel beams **232** can be seen as part of the four vertical walls **212, 214, 222, 224** of the secondary container **200'**. A concrete floor slab **250** is provided under the walls **212, 214, 222, 224**. An upper roof structure **260** is peeled away to show equidistantly spaced roof trusses **262**.

[0059] The secondary container **200** of **Figure 1** employs vertical wall structures. Preferably, the first and second end walls **212, 214** and the side walls **222, 224** are erected on-site over the secondary tank bottom **225**. Each wall is substantially vertical and, preferably, substantially planar.

[0060] To aid in the efficient erection of the various walls **212, 214, 222, 224** prefabricated panels are preferably employed. **Figure 3** shows a series of individual panels **230'** that may be used for assembling vertical walls of the secondary container **200**, in one embodiment. The vertical panels **230'** are a combination fabrication, meaning that they are formed from a combination of steel and concrete. In the arrangement of **Figure 3**, each panel **230** has at least one I-beam **232** adjoined to a thin concrete plate **234**. The steel beam **232** may be prefabricated, or may be built-up by welding or otherwise attaching plates to form a beam. In one embodiment, the panels **230** are adjoined in such a manner that the beams **232** are spaced at 5 m intervals.

[0061] In one embodiment, the concrete plate **234** is pre-formed by pouring concrete into a mold, with the cured plate **234** being about 100 mm thick to about 500 mm thick. In another embodiment, the plate **234** is about 200 to 400 mm thick, or alternatively, approximately 250 mm to 350 mm thick. The I-beams **232** are attached to the concrete plates **234** along an outer surface **233** to provide lateral structural support. The laterally supported thin-wall arrangement has advantages over the thick, one-meter concrete walls sometimes seen in modern cylindrical tanks. In this respect, thicker walls induce large and prolonged through-thickness, non-linear, thermal gradients, resulting in large, thermally-induced stresses. The individual wall panels **230** may optionally be poured as a group of panels **230'**, such as 2, 3, 4 or more panels **230** to form a structurally monolithic panel **230'**. Thus, the "smallest building block" may be a panel **230**, or a panel **230'**.

[0062] **Figure 4** provides a top view of a portion of the panels **230'** of **Figure 3**. Visible in **Figure 4** are three spaced-apart I-beams **232** butted against concrete plates **234**. Metal plates **236** are optionally embedded into the concrete plates **234** for receiving additional layers onto the inner surface of the plates **234**, as will be

described below. In one arrangement, the embedded metal plates **236** extend 100 mm into the concrete plates **230**. Also visible in **Figure 4** are the ends of steel bars **237**. The optional steel bars **237** act as "rebar," and serve to reinforce the plate **230**.

[0063] **Figure 5** presents a single panel **230** from the panels **230'** of **Figure 3**, in one embodiment. The panel **230** represents one possible "smallest building block" of the combination wall units as might be used in constructing an LNG containment system **100**. A plurality of individual panels **230**, e.g., four, may be fabricated as a unit in a casting yard for delivery to a construction site. The number of "smallest building blocks," i.e., individual wall panels **230** or groups of panels **230'**, that are fabricated as a unit depends on a number of factors, such as casting yard capabilities and on-site handling and lifting equipment. In one possible arrangement, for a 95 m long x 45 m wide x 35 m high structure with concrete plate thickness of 350 mm and a steel beam spacing of 5 m, which is calculated to be a satisfactory secondary container in one embodiment of a 100,000 $m^3$ rectangular LNG containment system, a building unit of four "smallest building blocks" is preferred.

[0064] **Figure 6** is a perspective view of the panels of **Figure 3**, seen from the opposite side. Here, inner faces **231** of the combination panels **230'** are seen. A group of panels **230'** are fabricated as a single unit. Each inner face **231** may receive additional layers onto the concrete panel **230**. First, a moisture barrier **242** may be placed onto the inner face **231**, i.e., along the concrete panel **230'** opposite the at least one steel beam **232**. The moisture barrier **242** is preferably fabricated from either a metallic material or a polymeric material. Second an insulation layer **244** may be disposed on the moisture barrier **242**. Preferably, the insulation layer **244** is a 5 cm layer of a cryogenic insulation material such as polyurethane foam. The insulation layer **244** helps to lessen the severity of initial thermal gradient during a thermal shock event, and to limit the temperature extremes that the wall is subjected to. Finally, a liner plate **246** may be placed onto the panel **230'**, preferably over the insulation layer 244. The liner plate **246** is preferably a nickel steel alloy, such as a 5-6 mm thick plate of 9% Nickel steel. In **Figure 6**, layers of a moisture barrier **242**, an

insulation layer **244**, and a liner plate **246** are shown exploded from the concrete panels **230'**.

**[0065]** As noted, the various combination panels **230** are joined to form a wall of any desired length. When assembling walls **212, 214, 222** and **224** for the secondary container **200**, the panels **230'** are erected in a vertical orientation over a floor slab, such as a concrete floor slab. A floor slab is seen at **250** in **Figure 1**. The floor slab **250** provides a fixed base for the containment structure **100**. The floor slab **250** preferably has a 9% nickel steel or other cryogenic material liner **225** on top to cover the foundation slab **250**. Additionally, the floor slab may have a moisture barrier and an insulation layer on top of the foundation slab **250** as previously discussed for the concrete panels **230'**. Such a combination of liners may also be placed on the end and side walls up to a height of 3 to 5 meters as corner protection against thermal expansion.

**[0066]** The steel beam/concrete combination walls **212, 214, 222, 224** are connected to the floor slab **250**. In one embodiment, a "pin" connection is provided between the panels **230'** and the slab **250**. The liner plate **246** on the panels **230** is joined to the liner plate **225** on secondary tank bottom **250** such that a liquid tight secondary containment is obtained. The steel beams **232** and the exterior surface **233** of the panels **230'** are in some instances coated with fire proofing materials to enhance their integrity against fire.

**[0067]** In practice, the floor slab **250** receives not only the various end **212, 214** and side **222, 224** walls, but also supports the primary container **300**. Preferably, a bottom insulation layer is interposed between the concrete floor slab **250** and the steel inner tank bottom **225** by placing insulation materials (not shown) in the annular space (also not shown) between the inner **300** and outer **200** tanks.

**[0068]** The walls **212, 214, 222, 224** of the outer tank **200** of the present invention are designed to contain the liquid product, i.e., LNG, in the event of a large leak from the primary inner container **300**. The external vertical steel beams **232** carry a large portion of the hydrostatic loads of LNG if and when the liquid from the primary

tank **300** leaks out. The concrete sections **234** of the walls **212, 214, 222, 224** induce relatively small thermal stresses due to the thermal shock at initial contact with LNG. Preferably, the walls are "thin," having a thickness of about 100 mm to 500 mm. In one embodiment, the concrete plate **234** is 350 mm to 400 mm in thickness. The thin walls are capable of surviving the thermal shock loads without insulation or any other mitigation. A full height steel liner **246**, with a partial or full height insulation layer **244**, assures leak tightness and aids in stress management during thermal shock. By so splitting the functional duties of strength provision, liquid containment and liquid and gas leak tightness, and forbearance of thermal shock induced stresses, the wall structure achieves efficiency when contrasted with traditional solutions that ascribe fulfillment of all these requirements to a thick (e.g., greater than 600 mm), post-tensioned wall installed on a fixed concrete base.

**[0069]** **Figures 7A-7F** present sequential steps for assembling a panel **230** as may be used in the construction of walls for the secondary container **200**, in one embodiment. **Figure 7A** shows the placement of a steel I-beam **732**. The beam **732** defines an elongated support member. Preferably, the beam **732** includes one or more small pins **731**. The pins **731** extend along a side of the beam **732**, and are generally enveloped by concrete during panel fabrication. The pins **731** serve to further secure the beam **732** to the cured concrete plate, seen **FIG. 7F**). In **Figure 7A**, the beam **732** has been placed in a jig **735**. The jig **735** serves as the bottom formwork for supporting plate-forming operations.

**[0070]** **Figure 7B** presents a plurality of truss brackets **734** positioned transverse to the single I-beam **732** of **Figure 7A**. The truss brackets **734** provide a support for the wall panel fabrication operation. In the arrangement of **FIG. 7B**, form plates **733** have been laid on opposing sides of the beam **732**. Pins **731** extend upward intermediate the form plates **733**. The form plates **733** serve as an impermeable base over which concrete is later poured. The form plates **733** may become a permanent inner layer along the concrete plates **738**, though preferably they stay in the jig **735** and are not a permanent part of a panel **730**.

[0071] **Figure 7C** shows a next step in the panel-forming operation. Here, reinforcing cages **736** are being laid. The form plates **733** assist in supporting the cages **736**. The cages **736** are preferably fabricated from steel. The cages **736** receive poured concrete (see the panel-forming step of **FIG. 7E**). In this manner, the cages **736** serve as "rebar" to strengthen the formed panel.

[0072] A next step in the panel-forming operation is seen in **Figure 7D**. **Figure 7D** shows embedded plates **738** being placed over the edges of the cages **736** of **Figure 7C**. Reinforcing cages **736**, and embedded plates **738** are placed in the jig **735** and appropriately connected together by welding or fastening by other means. **Figure 7E** demonstrates the pouring of concrete in the formwork of **Figure 7D**. The concrete is allowed to cure to form a panel **730**.

[0073] Finally, **Figure 7F** shows the attachment of various layers **742, 744, 746** over the top surface of the cured concrete panel **730**. Layers may include a moisture barrier layer **742**, an insulation layer **744**, and a liner plate **746** placed over the concrete panels of **Figure 7E**. The moisture barrier **742**, the insulation layer **744**, and the liner plate **746** are again shown exploded from the concrete panel **230**. Preferably, these fabrication steps would take place in a concrete casting yard. After assembly, the precast wall sections **230** are moved to the construction site (not shown).

[0074] A roof structure **260** is also provided on the secondary container **200**. The roof structure **260** may be assembled by adjoining roof panels in side-to-side (including end-to-end) fashion as with the wall panels described above.

[0075] First, referring again to **Figure 2**, this **Figure** shows an additional perspective view of an illustrative secondary container **200'**. In accordance with the above descriptions, a plurality of steel beams **232** is provided along vertical end walls **212, 214** and side **222, 224** walls of the secondary container **200'**. In addition, an upper roof structure **260** is provided. The roof structure **260** is convex relative to the exterior of the container **200'**, and in this embodiment forms a shallow arch. In the view of **Figure 2**, the roof structure **260** is peeled away to show several spaced-apart roof trusses **262**. The roof trusses **262** span the secondary container **200** across the

opposing side walls **222** and **224**. Concrete panels **266** are placed over the trusses **262**. A carbon steel plate **264** spanning the entire width and length directions of the secondary container structure **200** is optionally under the concrete panels **266**. As noted above, the roof structure **260** may be fabricated by adjoining pre-poured concrete roof panels in side-to-side fashion. Alternatively, the roof structure **260** may be formed by first installing the trusses **262**, followed by installation of the liner **264,** and then pouring a topping layer of concrete on top of the liner **264**. The concrete is poured in place with the liner **264** serving as part of the formwork.

**[0076]** **Figure 8** provides an enlarged perspective view of a portion of the containment system **200** from **Figure 2**. Visible in this view are the steel trusses **262** with thin, reinforced concrete roof panels **266** having been placed there over to form the roof structure **260**. A moisture barrier plate **264** is again disposed between the trusses **262** and the concrete plates **266**. Vertical side panels **230** in accordance with the panels **230** of **Figure 3** are also visible, supporting the steel roof trusses **262** and forming a side wall **224**.

**[0077]** The roof structure **260** of the secondary container **200** is a steel/concrete combination construction. In the embodiment of **Figures 2** and **8**, the roof structure **260** is shaped to provide a shallow arch configuration in the width direction of the structure **200**. Uniformly spaced steel trusses **262** spanning the width of the secondary container **200,** with their spacing matching the spacing of the vertical steel beams **232** of the side walls **222, 224** are attached to these beams **232** at their upper termini. A carbon steel plate **264** spanning the entire width and length directions of the secondary container structure **200** is installed atop and attached to the upper extremities of the roof trusses **262**. The carbon steel plate **264** serves as the moisture and vapor barrier when the structure **200** is completed. A layer of reinforced concrete **266** is installed over the trusses **262** and the carbon steel plate **264**.

**[0078]** The roof structure arrangement **260** of **Figures 2** and **8** allows partial prefabrication. In this respect, the steel trusses **262** and steel plate **264** may be fabricated off-site. A roof "building block" may be composed of two, three, or more trusses. These "prefabricated truss panels may be delivered to the tank construction

site to aid in a more efficient secondary tank construction operation. For example, first the steel truss **262** and steel plate **264** roof building block may be installed so that the steel trusses **262**, with their spacing matching the spacing of the vertical steel beams **232** of the side walls **222**, **224**, are attached to these wall beams **232** at their upper termini. Then the concrete plates **266** of the roof structure **260** may be formed by pouring concrete on top of the steel plate **264** of the roof building block. Post tensioning of the roof concrete layer **266** may not be necessary in these arrangements.

**[0079]** In addition to providing a secondary container for an LNG containment system **100**, a method is also provided herein for assembling an LNG containment system, such as system **100**. Construction of containment system **100** is expedited by using the above-described secondary container embodiments **200**. The secondary container **200** is erected over a concrete tank floor (seen at **250** in **FIG. 1**). More specifically, individual walls, e.g., end walls **212**, **214** and side walls **222**, **224** are formed by vertically erecting and attaching various panels (shown at **230** in **FIG. 3**) side-by-side. This is a segmental technique that uses off-site prefabrication of building blocks that can be assembled into a structural system.

**[0080]** Known full containment systems typically demand a relatively long construction schedule. The sequential construction of storage system elements normally starts with the construction of a cast-in-place outer tank slab and walls. Only after the domed roof has been constructed on the outer tank walls is construction on the internal structures, including the bottom insulation and inner steel tank, started. This means that the inner steel tank is constructed in-situ after the secondary container has been at least substantially completed. A construction schedule of 36 months for a now typical 160,000 $m^3$ full containment LNG storage tank is normal. This long construction schedule is often on the critical path for an LNG facility construction project, causing a potential source of delay. Therefore, an improved method for assembling an LNG containment system is offered.

**[0081]** **Figures 9A-9F** present sequential steps for construction of a full containment LNG tank **100**, in one embodiment. The full containment tank **100** will include one or more inner tanks **300** and a surrounding outer tank **200**. First,

**Figure 9A** shows the formation of a concrete floor slab **250**. In this embodiment, the "footprint" of the slab **250** is rectangular. In addition, a vertical end wall **212** has been erected over an end of the floor slab **250**. The end wall **212** has been assembled by adjoining prefabricated combination wall panels (such as those shown at **230** in **Figure 3**) in side-to-side fashion. The wall panels **230'** may be individual wall panels **230**, or may be a structurally monolithic collection of wall panels **230'** fabricated in a casting yard to form a single "panel." The wall panels **230** are tilted up into vertical position using lifting equipment (not shown). The panels are aligned and braced, and interconnected to form the end wall **212**. Structural connection between the floor slab **250** and the wall panels **230** forming end wall **212** is then provided.

**[0082]** In **Figure 9A**, scaffolding **310** has been erected. The scaffolding **310** assists in the lifting, aligning, bracing and interconnecting of prefabricated wall panels **230'**. However, the methods for constructing an LNG containment system claimed herein are not limited in scope by the type of equipment used for the construction.

**[0083]** Next, panels forming the side walls **222, 224** are installed similar to the end wall **212**. This means that the side walls **222, 224** are lifted up into vertical position. The side panels are aligned and braced, and interconnected to form the respective side walls **222, 224**. The side walls **222, 224** are then connected to the floor slab **250** and the adjoining panels of the end wall **212**. In **Figure 9A**, a first wall panel **230'** is seen being raised for a side wall.

**[0084]** Construction of a roof structure **260** follows closely behind the side wall construction. In one embodiment, prefabricated combination roof panels (such as those shown at **260'** in **Figure 9B**) are erected onto wall panels **230'** as the side walls **222, 224** are being formed. **Figure 9B** presents the placement of a prefabricated roof panel **260'** on the concrete floor slab **250**. As sufficient numbers of side wall panels are installed, the roof truss units with concrete plates (roof panels **260'**) are brought in, lifted in place and structurally connected to the walls **222, 224** and adjoining roof panels **260'**. Construction continues until one end wall **212**, two side walls **222, 224** and a roof structure (seen at **260** in **Figure 9C**) is completed.

[0085] **Figure 9C** is a cutaway view of the secondary container **200**. In this step, the two opposing side walls **222, 224** have been erected along the floor slab **250**. In addition, a roof structure **260** has been placed over the span between the two opposing side walls **222, 224** to define the secondary container **200**. One end of the secondary container **200** is left open for installation of the inner tank **300**. A substantially complete primary container **300** has been moved into its position within the secondary container **200**. The inner tank may be insulated by providing a bottom insulation layer interposed between the concrete floor slab and steel tank bottom.

[0086] Figure **9D** shows another primary container **300** being rolled into the secondary container **200**. In this respect, a secondary container may hold more than one primary container, in a linear arrangement.

[0087] **Figure 9E** demonstrates that the second primary container **300** has been substantially moved into the secondary container **200**. Additional insulation materials may be placed in an annular space (not shown) formed between the inner **300** and outer **200** tanks.

[0088] Finally, **Figure 9F** shows the erection of the second vertical end wall **214** to form the enclosed secondary container **200**. The two parallel tracks **11** have been removed. A full containment LNG container system **100** has been assembled in an efficient manner. The above procedure permits parallel construction of the inner **300** and outer **200** tanks, thus reducing the construction schedule considerably.

[0089] A description of certain embodiments of the inventions has been presented above. However, the scope of the inventions is defined by the claims that follow. Each of the appended claims defines a separate invention, which for infringement purposes is recognized as including equivalents to the various elements or limitations specified in the claims.